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Are there arbitrage gaps in the UK gilt strips market?

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Abstract

Evidence in financial markets of an opportunity for pure arbitrage, and therefore a violation of the law of one price, is considered an anomaly to be noted. This paper reports an apparent violation of the law of one price between UK government gilts and their separately traded principal and coupon strips over a sample period of nearly 14 years. There are persistent price differences, and hence opportunities for arbitrage, after allowance for the bid-ask spread; the strips package tends to be overpriced in relation to the corresponding gilt. The price differences may, in part, be due to a lack of liquidity and stale prices in the strips market.

JEL classification: G14; G19
Keywords: Gilt; Arbitrage; Anomalies; Law of one price; Market microstructure

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Are there arbitrage gaps in the UK gilt strips market?

1. Introduction

One of the fundamental tenets of the received theory of finance is that arbitrage opportunities should not persist, or equivalently, that the law of one price should prevail. In the context of financial markets, no-arbitrage in the strong sense means that two assets that are freely traded and have exactly the same payoffs should cost the same. This principle is fundamental because it assumes a minimum standard of rationality and awareness on the part of market participants.

There is a weaker notion of no-arbitrage, implied by the principle of market efficiency, under which assets that do not provide the same payoffs should nevertheless be priced in a consistent manner.[1] The behavioural finance literature points out that individuals often do not, in practice, value assets and make decisions in the fully rational manner assumed by classical finance theory. The 'mistakes' that people make could have the consequence that market prices do not always reflect all publicly available information, and that no-arbitrage in the weaker sense does not hold.[2] However, the psychological traits pointed out in behavioural finance, such as overconfidence, or aversion to realising losses, tend to result in mistakes which have degrees of subtlety. They involve what might be called errors of judgement.

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[1] Using the concept of payoffs in future states of the world, no-arbitrage in the weaker sense means that the price today of one unit of payoff in a given future state x is the same across all assets with state-contingent payoffs that include a payoff in the state x. Of course, if no-arbitrage in the strong sense does not hold, no-arbitrage in the weaker sense cannot hold either. See Arrow (1964) or Myers (1968).

[2] See, for example, Shleifer (2000) or Shiller (2003), for reviews.

A key point about no-arbitrage in the strong sense is that someone who fails to exploit a pure arbitrage opportunity is apparently making a basic error or oversight. The opportunity should be obvious, the trades required to exploit it will involve zero or minimal risk, and if short-selling is possible the trades need involve no change in an arbitrageur's holdings of securities. Examples where no-arbitrage appears to be violated are, therefore, both puzzling and potentially helpful in developing our understanding of how financial markets work in practice.

Several papers have presented evidence that pure arbitrage opportunities can persist in financial markets, after making careful allowance for transaction costs, taxes, and other frictions which might mean that a given arbitrage opportunity is illusory. Grinblatt and Longstaff (2000) using US data, and Halpern and Rumsey (2000) using Canadian data, find that there are valuation differences between government bonds and the corresponding packages of strips which provide exactly equal cash flows. Grinblatt and Longstaff conjecture that factors such as liquidity, maturity and taxation might explain part of the persistence in the valuation differences. Arbitrage does not appear to eliminate the residual. Other cases of apparent pure or near-pure arbitrage opportunities include gross mispricing of shares in equity carve-outs (Lamont and Thaler, 2003), and differences in price for dual-class shares with the same entitlements to cash flows (Schultz and Shive, 2010). Lamont and Thaler present evidence that the short selling required to exploit arbitrage opportunities in the carve-outs they study was difficult because of a shortage of lendable shares, although this does not explain why some investors were willing to buy the grossly overpriced security. Shultz and Shive do not identify any particular obstacles to arbitrage between dual-class shares, but their evidence suggests that arbitrage trading is for some reason limited in scale, despite the apparent opportunities for riskfree profit.[3]

The current paper investigates whether there are persistent arbitrage opportunities in the UK gilts and strips markets. Since the introduction of the UK's Official Gilts Strips Facility in December 1997, it has been possible for certain UK gilts to be 'stripped'. The introduction of the Gilts Strips Facility was motivated, at least in part, by a desire to improve liquidity (Bank of England, 1997). The conventional gilt is exchanged for its constituent coupon and principal cash flows (strips), which can then be traded individually. If there is a valuation difference between a conventional gilt and its equivalent strips package, this arbitrage gap should be easy to identify and exploit. Yet we find that there are valuation differences between gilts and the equivalent strips packages in the UK gilts market. Arbitrage could be impeded by transaction costs, giving a false appearance of the failure of the law of one price. Our study suggests that persistent arbitrage gaps remain after transaction costs are accounted for, and the gaps do not appear to be explained by personal taxes. In particular, we find that strips packages tend to be overpriced in relation to the corresponding gilt. The results are therefore similar in spirit to those in the papers cited above, and Schultz and Shive (2010) also find that it is the less liquid security that tends to be overpriced. The results point towards the existence of market inefficiencies or frictions, or behavioural features that are not fully understood as yet. Gilt-edged market makers should be well-placed to exploit arbitrage opportunities, and it is puzzling why they appear not to do so more effectively.

[3] Other opportunities for arbitrage, in a weaker sense, have been documented for the shares of dual-listed companies (for example, De Jong, Rosenthal and Van Dijk, 2009) and of closed-end funds (for example, Gemmill and Thomas, 2002). The opportunities in these cases are not pure arbitrage, as they

A partial explanation for our results could arise from the fact that the strips market is much less liquid than the gilts market. We report evidence indicating that strips prices are stale compared with gilts prices: strips prices do not change as frequently. The presence of stale prices in the strips market increases doubts about the extent to which substantial trades to exploit price differentials are feasible in practice. The prices in our dataset are averages calculated from the midpoints of bid-ask prices quoted by market makers, and the quoted prices are good for trades up to a certain size. But it may not be possible to exploit the apparent arbitrage opportunities on a large scale, and perhaps not on a large enough scale to be worth the effort.

A question from our findings is why strip packages are overpriced much more often than are the corresponding gilts. There is no obvious reason why stale prices should lead to this result. The incidence of apparent arbitrage opportunities is positively related to time to maturity of the relevant gilt, possibly because more individual transactions are required to implement an arbitrage trade, with greater inconvenience and execution risk. The required arbitrage position involves short selling the strips packages, and it could be that this is problematic in practice.

The paper is organised as follows. Section 2 explains the Gilt Strips Facility. Section 3 describes the data and examines the influence of factors which could give the false

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require maintaining an open trading position for an uncertain period of time, which therefore involves some risks.

appearance of violations of the law of one price in the UK gilts and strips markets. Section 4 concludes.

2. The Official Gilts Strips Facility

The Official Gilts Strips Facility, introduced in the UK on 8 December 1997, allows conventional gilts to be 'stripped' of coupons. The conventional gilt can be exchanged for a series of coupon strips and a principal strip which together replicate exactly the cash flows of the original gilt and can then be traded separately. For example, the 8% Treasury Stock 2021 promises a future semi-annual coupon payment of £4 per £100 of face value, payable on 7 June and 7 December each year until maturity, together with repayment of the face value on 7 June 2021. An investor who stripped this gilt would therefore receive a number of coupon strips corresponding to the remaining coupon payments, and a single principal strip.

The Gilt Strips Facility enables investors, via gilt-edged market makers (GEMMs) or the Bank of England, not only to separate coupon-bearing gilts (conventionals) into separately tradable zero-coupon and principal instruments (strips), but also to reconstitute strips into the original coupon-bearing gilt. It is necessary to hold all the strip components to reconstitute the instruments into the original gilt. To facilitate reconstruction, coupon strips are fungible in that coupon strips due on the same date are interchangeable regardless of which conventional gilt they arose from. GEMMs are obliged to post daily bid and ask prices for coupon strips as well as gilts, which ensures that trading is possible within the size limit for which a given quote is valid, although our results suggest that quoted prices may, at times, be stale.

A rationale for allowing stripping is that strips can be used to create synthetic assets whose cash flows could not be achieved using only conventional gilts (Ahmad and Lal 2006; Grinblatt and Longstaff 2000). Thus strips are useful in hedging interest rate risk. Strips may be more attractive to fund managers in that they have higher duration than conventional gilts with the same maturity, are more convex, and offer exposure to specific points on the yield curve (Deacon, 2000).

The before-tax cash flows of the conventional gilt and the package of the stripped coupons and principal are identical. In the absence of transaction costs and tax distortions, therefore, the prices of the conventional gilt and the equivalent strip package would be identical in a fully efficient capital market. If there are differences in the prices that are not accounted for by factors such as liquidity and taxation, and that exceed the transaction costs involved in exploiting the price differential, then investors could earn arbitrage profits from suitable transactions in the conventional and stripped gilts markets. If the package of strips is overpriced compared to the conventional gilt, the strip package could be sold short and the proceeds used to purchase the conventional gilt. The conventional gilt would then be stripped and the short sale position in each of the strips would be closed. Conversely, if the package of strips is underpriced compared to the conventional gilt, the conventional gilt could be sold short and the proceeds used to purchase the strip package. The strips would then be reconstituted to close the short position in the conventional gilt. A market participant wishing to transact a short sale would need to be deemed reliable and creditworthy by the GEMM lending the security, which means that such a transaction might not be possible for all participants. But short selling is an established practice in government bond markets, which most institutional investors should be able to undertake.[4]

The requisite trades can be executed almost simultaneously, so any gain from them is almost risk-free and can be realised immediately. However, a number of separate transactions in strips is necessary to implement an arbitrage trade, and the number is positively related to the maturity of the gilt. The investor would need to monitor settlement of the requisite transactions. To strip a gilt, for example, the investor would have to transfer the gilt from the investor's Crest (securities depository) account to that of the GEMM, and the GEMM would have to transfer the resulting component strips from the GEMM's account to that of the investor. Arranging an arbitrage position would therefore involve an administrative burden. In addition, it might be difficult for a short seller of strips to find strips to borrow, since the volume of strips outstanding is much lower than the volume of gilts. In practice, the market participants best able to carry out arbitrage trades are the GEMMs themselves.

3. Data and results

3.1. Price differentials ignoring costs of trading and tax

The data on prices are taken from the UK Debt Management Office (DMO) database for the period 08 December 1997 to 25 November 2011 inclusive. The prices are reference prices calculated by the DMO from midpoint prices submitted by GEMMs at the end of each

[4] According to a review of short selling written on behalf of professional investors, 'Market participants are able to short sell [on an uncovered basis] a government bond to take advantage of a trading opportunity with a high degree of confidence of being able to cover that position by borrowing the asset when they need to do so. For example, in the UK borrowers typically borrow the bonds within 24 hours of selling' (International Securities Lending Association, 2010, p. 20).

trading day.[5] A midpoint price should, by its nature, be in between the bid and ask prices quoted by the GEMM for the relevant gilt, at which it is willing to trade. Of the 44 conventional gilts for which data are available, eight were strippable from the beginning of the sample period, when the Gilts Stripping Facility was introduced, with further strippable gilts issued each year during the sample period (Table 1). The coupons on the strippable gilts range from 4.00% to 8.50%, and the remaining times to maturity at the time the gilts entered the sample range from 2.95 to 50.00 years. Daily reference prices for the principal and coupon strips required to replicate the cash flows of the 44 conventional (strippable) gilts are similarly obtained from the DMO database.[6] For each daily price observation for a conventional gilt, the value of the corresponding replicating portfolio of principal and coupon strips was calculated, giving a total of 65,500 pairs of observations. We exclude 16 outlying observations as they appear to be due to obvious data-entry errors.

[TABLE 1 APPROXIMATELY HERE]

To examine the valuation differences, the value of the replicating package of gilt strips is compared with the price of the corresponding conventional gilt. We refer to this as the strip-conventional *price differential*. The strip package is overvalued in relation to the

[5] 'At the end of each business day, each GEMM sends the DMO a set of mid-market closing prices for those gilts in which it makes markets... From these prices the DMO computes an average price for each gilt and then publishes this reference price... For a given gilt the reference price is not intended to give a market price at which it could be traded, but provides an indicative price' (DMO website, www.dmo.gov.uk/index.aspx?page=Gilts/Daily_Prices, accessed on 11 January 2012). Because an average will normally contain higher and lower prices, the data will tend to underestimate any arbitrage opportunities that may be present.

[6] In this respect our dataset is superior to that of Halpern and Rumsey (2000): they have to estimate the prices of Canadian strip packages from the term structure of observed bid yields for strips. Also,

conventional gilt when the differential is positive, and undervalued when the differential is negative. A non-zero strip-conventional price difference does not necessarily give rise to an arbitrage opportunity, however, as the costs of arbitrage may exceed the potential benefit. Before examining the costs of arbitrage, we consider the extent of the price differentials in Table 2.

[TABLE 2 APPROXIMATELY HERE]

This table provides descriptive statistics about the price differential. The statistics for the entire data sample are presented in Panel A. The sample is then segmented into three sub-periods of equal length, in Panels B through D. Within each panel, the data are also segmented by gilt maturity using the standard classification of short (< five years to maturity), medium (five to 15 years to maturity) and long (> 15 years to maturity) on the relevant observation date.

The mean (median) price differential over the entire sample period is £0.060 (£0.017) per £100 of face value, which is significantly different from zero (t = 51.6). This indicates that, on average, replicating packages of gilt strips are overvalued relative to the corresponding conventional gilt. The mean differential is positive for all gilt maturities in all three sub-periods. But it is smaller for short-dated gilts than for medium- and long-dated gilts. The means by quintile of price differential show that the incidence of large absolute differentials,

both Halpern and Rumsey (2000) and Grinblatt and Longstaff (2000) use monthly data, whereas we have daily prices.

positive or negative, tends to be highest for long-dated gilts. We discuss possible reasons for these findings below.

In the Canadian market, bonds were more often overpriced rather than strips packages, until about one year after May 1993, the month from which arbitrage trades became much easier to execute (Halpern and Rumsey, 2000). There was no difference on average between the prices of US bonds and their strip packages during 1990-94 (Grinblatt and Longstaff, 2000).

3.2. Estimation of bid-ask spread

Data on the typical bid-ask spread for gilt strips is unavailable. Whereas Halpern and Rumsey (2000) use a range of possible bid-ask spreads, and Grinblatt and Longstaff (2000) ask Wall Street traders for estimates of the bid-ask prices, this paper uses actual data to estimate the spread. Following Roll (1984), the *average* bid-ask spread is proxied by the following equation:

$$Bid - Ask = 2\sqrt{-\mathrm{cov}} \tag{1}$$

where the term cov is the first-order serial covariance of price changes. This first-order serial covariance would be expected to be negative if bid-ask bounce were present in the price series.

We note that the raw data on both the conventional and replicating packages display positive serial dependence due to the presence of an increasing price trend. The following factors may potentially explain this upward trend:

i. drag to par as the gilts move towards maturity, and

ii. the sample covers a period when interest rates were generally falling, which would have an inverse effect on gilt prices.

To account for the above factors we follow the procedure outlined below. First we compute the 'expected change in price', $E\Delta$, using gilt yield-curve data published by the Bank of England. The expected change in price of £1 face value of a coupon or principal strip payment i occurring m years in the future is as follows:

$$E\Delta_{£1,T} = e^{-m_{i,T} y_{i,T}} - e^{-m_{i,T-1} y_{i,T-1}} \tag{2}$$

where $m_{i,T}$ is the time (in years) from day t to payment i on day T, and $y_{i,T}$ is the continuously compounded yield corresponding to $m_{i,T}$. The expected change in price for conventional gilt j from day t–1 to day t is then simply the sum of the expected changes in price of each of its component cashflows:

$$E\Delta_{j,t} = \sum E\Delta_{£1,T} C_{j,T} \tag{3}$$

where $C_{j,T}$ is the cashflow to gilt j on day T. For both the conventional gilt and each individual strip component, $E\Delta_t$ is deducted from the observed daily change in gilt prices to obtain the unexpected change in price as follows:

$$U\Delta_{j,t} = p_t - p_{t-1} - E\Delta_{j,t} \tag{4}$$

where $U\Delta_{j,t}$ is the unexpected change in gilt price j from day t-1 to day t, and p_t is the price of the gilt on day t.

Using the computed values of the unexpected changes in prices, we calculate the one trading-day serial covariance of unexpected returns for each of the strip packages and the conventional gilts. Only one strip package, the long-dated coupon strip maturing 7 June 2032, exhibits positive serial covariance. For this coupon strip, the Roll methodology fails. For each of the remaining gilts and strips packages in the sample, the one-trading-day serial covariance is negative as expected, and we use the Roll methodology to calculate the implied bid-ask spreads.

The resulting implied bid-ask spread to execute an arbitrage trade, rounded to the nearest basis point, is ten basis points. The actual bid-ask spreads faced by individual traders in the gilt market will vary based on the identity of the trader and the size of the transaction, as well as market conditions at the time, hence we consider it appropriate to use an average value of ten basis points to approximate the bid-ask spread when interpreting whether the extent of the strip-conventional price differentials highlighted in Table 2 may represent unexploited arbitrage opportunities.

3.3. Price differentials net of bid-ask spread

[TABLE 3 APPROXIMATELY HERE]

Table 3 reports the number of observations, by time to maturity of the conventional gilt, in which the price differential exceeds the implied bid-ask spread of £0.10 per £100 of face value. The mean differentials net of the spread are also reported for each maturity category. The means of positive and negative values of the differential are reported separately in order to highlight possible maturity bands for which strips packages are systematically overvalued or undervalued in relation to the corresponding conventional gilt. This may occur, for example, if there is particular demand from investors for zero-coupon gilt strips falling in specific maturity bands. Table 3 indicates that price differentials persist even after accounting for the bid-ask spread, highlighting a possible violation of the law of one price.

After adjusting for the spread, the gilt is underpriced (strips overpriced) in 13,821 cases and overpriced in 3,651 cases. The price differential is within the spread for the remaining 48,028 cases. Whilst there are many cases across all maturities where conventional gilts are both underpriced or overpriced, patterns can be observed in the relative frequencies of positive and negative strip-conventional price differentials. The proportion of observations in which the differential is within the spread tends to decrease with time to maturity of the gilt, especially for gilts with longer than seven years to maturity. Ninety-nine percent of the differentials are within the spread for gilts with less than one year to maturity, compared with 25% for gilts with between 40 and 50 years to maturity. The proportion of overpriced strips is higher than the proportion of overpriced gilts for all maturities except two to four years. The relationship between the proportion of overpriced strips and maturity increases almost monotonically, but the proportion of overpriced gilts stays below 8% for maturities of up to 30 years, and then jumps to 15% for maturities of 30 to 40 years, and 34% for maturities of 40 to 50 years.

The means of the price differentials by maturity category show that the largest differentials are found in maturities of 30 years or more for gilts (ignoring the two observations for gilts of less than one year). These overpriced long-maturity gilts account for 39% of all the overpriced gilts. For overpriced strips, the largest mean price differentials are for the shorter maturities, of up to four years. However, such overpriced short-maturity strips only account for 2% of all the overpriced strips. The bulk of the overpriced strips arise at maturities of at least 10 years, and the mean differential net of the spread for these overpriced strips is quite high (around £0.20 per £100).

There are two potential additional costs facing an investor engaging in arbitrage, namely capital gains tax on the arbitrage gain, and commission costs. These costs will differ substantially depending on the type of investor. For example, an individual might have to pay tax on an arbitrage gain whereas a tax-exempt investor such as a pension fund will pay no tax. The percentage commissions on large institutional trades, if any, are very much lower than on trades of a few thousand pounds by individuals, and a market-maker will pay zero commission. A high tax-bracket individual investor is likely to face the highest cost of arbitrage.

[TABLE 4 APPROXIMATELY HERE]

To illustrate the potential maximum impact of capital gains tax and commission, Table 4 shows the potential profits available from arbitrage trades of £10,000 in three gilts and their strips packages, with a differing trade date for each gilt. The gross gains in the table are at the high end of the sample, but they are by no means the largest gains. The costs consist of capital gains tax on the arbitrage gain, at the then prevailing rate of 40%, and trading commission of 0.5375% on the £10,000, as well as the estimated bid-ask spread. The costs combined absorb between 68% and 98% of the potential gains, so they are substantial.

However, we emphasise that these costs represent a maximum; institutional investors and GEMMs will face much lower costs.[7]

3.4. Do prices differentials induce arbitrage trades?

[TABLE 5 APPROXIMATELY HERE]

We examine next whether there is a connection between the extent of price differentials and possible arbitrage trades. Table 5 shows for each gilt in the sample the frequency of positive and negative price differentials net of the bid-ask spread, their average magnitude, and stripping and reconstitution activity levels for the period from 29 September 2003 for which stripping data are available. The reason for examining individual gilts here in Table 5 is to allow a comparison to be made between the level of stripping and reconstitution activity, and the extent of both underpricing and overpricing of the gilts. If there is a high level of stripping/reconstitution activity, arbitrage might be occurring and opportunities for gain might be eliminated fairly rapidly. We might therefore expect to observe smaller price differentials for strippable gilts where the level of stripping and reconstitution activity is high. Alternatively, it is possible that arbitrageurs will only engage in trading if the price differential is particularly large, and a higher mean differential may therefore persist even where the level of stripping/reconstitution activity is high.

[7] Neither Grinblatt and Longstaff (2000) nor Halpern and Rumsey (2000) mention either capital gains tax on arbitrage gains, or trading commissions.

The table shows the mean price differential for days on which the gilt is overpriced, and for days on which it is underpriced. There is a significantly positive correlation coefficient of 0.294 (0.323) between the mean price differential and levels of stripping (reconstituting) activity for days on which the gilt is underpriced, and no significant relation for days on the gilt is overpriced. This is a crude measure because the mean differential and percentage stripped for each gilt are numbers calculated for the whole sample period. But the positive coefficient suggests that when the overpricing of strips is relatively high, both stripping and reconstituting take place, potentially to take advantage of the arbitrage opportunity. Grinblatt and Longstaff (2000, Table 4), on the other hand, find for the US market no relation between the proportion stripped per month and the price differential at the start of the month, and so they argue that the price differential does not induce arbitrage trading.

A further point evident in Table 5 is that the proportions of gilts that are stripped or reconstituted per year are very low, mostly less than 2%.[8] This compares with an average proportion stripped per month of 1.9% in Grinblatt and Longstaff's sample, which presumably gives a proportion stripped per year of 23%, much higher than for the UK.[9] If trading does take place to try to exploit arbitrage gaps in the UK market, it is on a small scale compared with the size of the gilts market.

[TABLE 6 APPROXIMATELY HERE]

[8] Six per cent of 6½% Treasury 2003 was stripped during the last ten weeks of its life, giving an annualised rate of stripping of 31%. We exclude this outlier from Table 5 as the figure is derived from a relatively small number of days.

[9] Grinblatt and Longstaff (2000, p. 1416) argue that the primary reason for the substantial stripping activity in the US market is not arbitrage, but 'fundamental economic functions in completing the

The difficulty of taking advantage of a price differential could be related to the maturity of the relevant gilt. A longer maturity requires more transactions in separate strips, which could imply greater inconvenience and execution risk, as mentioned in Section 2. If this is an important consideration, the incidence of apparent arbitrage opportunities should be positively related to the time to maturity of the relevant gilt.[10] We see from Table 3 that the incidence of arbitrage opportunities does increase strongly with time to maturity, especially for overpriced strips. The regression results presented in Table 6 further support a positive relationship between price differentials and maturity. The signed price differential and absolute value of the differential are both positively related to the number of strips in the strip package, and therefore to the maturity of the relevant gilt. So one reason for arbitrage gaps in gilts with substantial time to maturity could be difficulty of implementing the arbitrage trades. The remainder of the paper examines several other possible reasons for the existence of arbitrage gaps.

3.5. Illiquidity in the strips market

[FIGURE 1 APPROXIMATELY HERE]

The strips market is much less liquid than the gilts market. Turnover in strips has declined over time, as can be seen from Figure 1, and only small proportions of gilts are stripped, as

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market and overcoming frictions'. A question remaining is why stripping activity is so much higher in the USA than in the UK.

noted above. In the first quarter of 2002 turnover was £442.1bn in fixed-coupon gilts and £2.2bn in strips, and in the first quarter of 2011 turnover was £1,434.6bn in gilts and £0.1bn in strips (source: DMO website). The current section presents the results of several tests designed to discover whether illiquidity affects the reported strips prices from the DMO, and whether illiquidity might explain the apparent unexploited arbitrage opportunities that we have found.

The liquidity of an asset and its price are expected to be positively related, other things being equal. This is intuitive, and it is predicted by mainstream models of the impact of liquidity, such as Amihud and Mendelson (1986). Since strips are less liquid than gilts, we would expect a strips package to be underpriced compared with the relevant gilt. However, we have seen that strips packages tend to be *overpriced* compared with the gilt, and that the overpricing of strips is more common for medium and long gilts, for which more trades in strips are required in order to reconstitute the gilt.

Our finding that strips tend to be overpriced is in line with the evidence of Schultz and Shive (2010) regarding 'mispricing' (price differences) of dual-class shares with the same rights to cash flows. The shares with enhanced voting rights are less liquid than the normal shares, but it is the high-vote shares that tend to have the temporary higher price when the prices differ, despite their lower liquidity. The authors present evidence that temporary higher prices are not a reflection of any value of the extra votes. They note, as we do, that their findings are counterintuitive. They also present evidence that it is standard one-sided trades that eliminate

[10] It is also the case that bid-ask spreads are positively related to the maturity of the gilt. This is not allowed for in our results as we assume the same spread for all would-be arbitrage transactions. We

price differences, rather than two-sided long-short arbitrage trades, and they conjecture that there are difficulties in transacting arbitrage trades. In our sample, an arbitrageur seeking to exploit an overpriced strips package would have to sell short the strips. This is likely to be more difficult than selling short an overpriced gilt, which could help explain why it is strips which tend to be overpriced.

A different potential impact of illiquidity is on the synchronicity of prices. The prices quoted by GEMMs in the strips market might tend to be 'stale' in relation to gilts prices, ie strips prices might not change as frequently, because trades in strips are less frequent. The difficulty of trading in large amounts at the quoted prices, to exploit an arbitrage gap, is likely to be greater if the quoted prices tend to be stale. To investigate whether strips prices are stale, we run two tests that are similar to tests in Ahn, Boudoukh, Richardson and Whitelaw (2002), who compare stock-index prices with index futures prices.[11] The first test is to compare the autocorrelation of daily returns; prices which are stale should result in a higher positive autocorrelation of returns. The second test is to estimate the following regression model for each gilt and strips package:

$$R_{stripj,t+1} - R_{giltj,t+1} = \alpha_j + \beta_j R_{giltj,t} + e_{j,t+1} \tag{5}$$

where $R_{giltj,t}$ is the return on the gilt j on day t, $R_{stripj,t+1}$ is the return on the corresponding strip package, and $e_{j,t+1}$ is the error term. If strips prices are stale, ie they lag the prices for the gilt, the β_j coefficient should be positive.

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thank the referee for pointing this out.

[11] A third test in Ahn et al (2002) requires data on daily trading volume, which we do not have.

Ahn et al (p. 673) argue that, if transaction costs impede arbitrage, different patterns of returns, including different autocorrelations and lead-lag relations, can prevail in pairs of assets whose prices should be locked together by arbitrage. The markets for each asset will be separate, to an extent. So, in the first test, impeded arbitrage leads to no prediction for the difference in autocorrelations, whereas stale strips prices imply greater autocorrelation of strips returns. Similarly, in the second test, impeded arbitrage leads to no prediction for the sign of β_j in equation (5), whereas stale strips prices imply a positive sign. Therefore, the higher the proportions of positive strips-gilt autocorrelation differences, and of positive betas, across the sample of gilts, the stronger the evidence for stale prices.

[TABLE 7 APPROXIMATELY HERE]

The results of the tests are presented in Table 7. Both the gilts and the strips returns display positive autocorrelation in the majority of cases, and the coefficients are positive and significant at the 10% level or more for 14 of the 44 gilts and 19 of the equivalent strips packages. Drag to par as the gilts move towards maturity is a factor which induces positive autocorrelation in both gilts and strips returns, as noted above. The autocorrelations are higher for 33 of the strips, but only seven of the differences are significant at the 10% level or more. We also calculate autocorrelations for returns with lags from two days up to five days (not shown). There is no clear difference between the autocorrelations for strips and gilts for the longer lags. Overall, the differences in the autocorrelations provide moderately strong evidence that strips prices are stale.

The evidence from the second test, equation (5), is stronger. All the beta coefficients are positive as would be expected if strips prices are more stale than the prices of conventional gilts, and all except one are highly significant at the 1% level or more. The results of both tests point in the same direction, and so we conclude that strips prices have a tendency to lag gilts prices.[12]

If the strips market is illiquid, and lack of arbitrage means that prices are not closely tied to gilts prices, then demand pressure for certain strips could have an observable impact on their price. It is plausible that the demand for a package of gilt strips is at its greatest when the gilt first becomes strippable. In some cases, strips will become available with new maturity dates, not previously covered by existing strips, and there might be one-off demand from investors seeking zero-coupon securities with such maturity dates. In order to test this idea, we calculate the percentage of price differentials in which the strips package is overpriced during the first year in which the relevant gilt became strippable, and the mean of all the price differentials, positive and negative, during this first year. 30.7% (11.4%) of the strips are overpriced (underpriced) during the first year the gilt is strippable, compared with 18.5% (4.5%) during subsequent years. The mean price differential is £0.054 for the first year, and £0.037 for subsequent years. The differences between these numbers are highly significant. They support the hypothesis that the attraction of strips is greatest when they first become available, and that demand-induced price differentials are not fully arbitraged away. Demand

[12] The DMO itself may have been concerned about stale prices from GEMMs, as it has recently changed the source of its prices for strips. 'From 3 October 2011, prices for STRIPS are calculated using the DMO's yield curve; these prices are not intended to represent market prices at which the securities could be traded (previous to this date, prices are based on end-of-day market price contributions by the GEMMs).' http://www.dmo.gov.uk/index.aspx?page=Gilts/Daily_Prices

pressure plus lack of arbitrage is also Lamont and Thaler's (2003) diagnosis of mispricing in certain equity carve-outs.

Finally, we investigate whether changes in liquidity over time, or differences in liquidity across strips packages, affect price differentials. We divide the sample period into three, as in Table 2, and compare the first subperiod with the last subperiod. If illiquidity is a cause of price differentials, we might expect the differentials to be greater in size and frequency during the last subperiod, as the lack of liquidity makes it harder to exploit apparent arbitrage opportunities. The results are in Table 8. The median differential is larger in the last subperiod for both overpriced strips and overpriced gilts, although the mean for overpriced strips is larger in the first subperiod. The percentages of observations for both overpriced strips and overpriced gilts are significantly higher for the later period. These findings provide some evidence that the decline in the liquidity of strips has increased the number of arbitrage opportunities which are not exploited.

Grinblatt and Longstaff (2000) find a positive relation between the price differential and the total proportion of the relevant bond that is held in stripped form. They interpret this as evidence for a liquidity effect on prices; a greater proportion held in stripped form implies greater liquidity in the relevant strips, and this is associated with a higher price for the strip package in relation to the price of the equivalent bond. In unreported analysis, we replicate the regression in Grinblatt and Longstaff's Table 3, using weekly and monthly observations. This regression tests for a relationship between the price differential and the proportion of the bond held in stripped form at a given date, in the presence of variables designed to control for the effects of possible measurement errors in the data.[13] The coefficient on the proportion held in stripped form is negative, which is not the expected sign, but it is not significant in either the weekly or monthly regression. The lack of explanatory power for this variable is perhaps not surprising, given the low proportions of UK gilts held in stripped form.[14]

3.6. Taxation

Gilts and strips are not taxed in an identical manner. Hence, whilst the cash flows of the conventional gilt and a package of the strips are identical before tax, they might not be identical after tax. This may lead, in the absence of arbitrage, to differences in trading value between conventional gilts and their corresponding packages of strips. However, the impact of tax is difficult to predict *a priori*. The types of investor which owned the largest amounts of gilts during the sample period are pension funds, life-assurance companies, and overseas investors. Pension funds are exempt from tax. Life companies receive interest gross of tax and then account for tax under a complicated 'investment income less expenses' regime, under which the tax paid on interest, if any, varies depending on the circumstances of the relevant life company. Overseas investors receive interest gross, and the tax they pay also varies depending on the investor. Individual investors own about 10% of the market, and interest on gilts is taxed as top-slice income. But many individuals will not pay any tax on

[13] The control variables are (i) the lagged value of the price differential, (ii) the change in the price of the gilt during the previous period, and (iii) the square of the change in this price. The rationale for these variables is discussed in Grinblatt & Longstaff (2000, pp. 1426-28).

[14] These regression results are available from the corresponding author on request.

their interest, because, for example, their gilts are held in a tax-exempt Individual Savings Account (ISA). Capital gains on gilts were exempt from tax during the sample period.[15]

Gains on holdings of gilt strips are treated as income. Investors are deemed to sell their strips on 5 April and repurchase on 6 April each year (6 April being the first day of the new UK tax year), and any resulting gains or losses are taxed as income. The amount of tax payable by investors in strips will depend on the gain in the strip price, if any, during the relevant tax year. If the coupon rate on a given gilt exceeds the yield on the gilt, investors paying income tax should prefer to hold the gilt in the form of strips (unless they can offset the expected capital loss over time on the gilt against capital gains tax). If the coupon rate is below the yield, the gilt should be preferred, as some of the return will be in tax-exempt capital gain (though this is not certain unless the gilt is held to maturity). On average over time, and in the absence of arbitrage, the tax argument would lead us to expect high-coupon gilts to be less highly priced in relation to the equivalent strips package than low-coupon gilts.

[TABLE 9 APPROXIMATELY HERE]

We first examine whether there is any relation between price differentials (net of the spread) and the coupon rate of the gilt. Table 9 shows mean price differentials for overpriced and underpriced gilts sorted by coupon. According to the preceding tax argument, high-coupon gilts should be more underpriced, or less overpriced, than low-coupon gilts. But there are no clear patterns. The proportion of overpriced strips is higher than the proportion of overpriced

[15] The taxation of gilts and strips is summarised briefly on the DMO website: www.dmo.gov.uk/index.aspx?page=Gilts/Gilts_Tax. For more detail, and for estimates regarding gilts

gilts for all categories of coupon. The proportion is highest for low-coupon gilts, which goes against the tax argument. There is no relationship between the mean price differentials and the coupon for either gilts or strips.

As a further test, we regress the price differential on the coupon rate of the gilt minus the prevailing yield on the gilt:

$$PD_{j,t} = \alpha_j + \beta_j(CR_{j,t} - Y_{j,t}) + e_{j,t} \qquad (7)$$

where $PD_{j,t}$ is the price of the strips package for gilt j on day t minus the price of gilt j, $CR_{j,t}$ is the coupon rate, $Y_{j,t}$ is the yield to maturity, and $e_{j,t}$ is the error term. If a higher value for coupon rate minus yield implies a greater tax disadvantage for the gilt, the coefficient on $(CR_{j,t} - Y_{j,t})$ should be positive. However, the coefficient is negative and significant ($t = -12.6$). Overall, our results suggest that tax cannot explain the price differentials that we observe.

4. Conclusion

This study examines price differentials between conventional gilts and their equivalent strips packages and finds that differentials exist after allowing for the bid-ask spread. If it is conjectured that transactions costs are not fully captured by the bid-ask spread in an illiquid market, then liquidity could play a role in explaining the apparent opportunities for arbitrage even after taking into account the bid-ask spread entailed in attempts at realising arbitrage profits. UK gilts are highly liquid, but the levels of stripping and reconstitution are low, and liquidity is much lower in the strips market. We find that strips are more often overpriced than underpriced compared with the relevant gilt, despite their lower liquidity. This could be

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ownership, see Armitage (2004). Ownership data are also available from the DMO website.

because of difficulties in short-selling strips in order to take advantage of the overpricing. The frequency of price differentials, in both directions, increases with the time to maturity of the gilt, which suggests that arbitrage becomes more problematic as the required number of transactions in individual strips increases. We find some evidence that the decline in the liquidity of the strips market has increased the likelihood that arbitrage opportunities are not exploited. The evidence does not support a tax-based explanation for the differentials.

There is no reason to believe that trades in strip packages cannot be transacted at or within the bid-ask spread that we have estimated. However, we find evidence that strips prices tend to lag gilts prices, presumably because of the lower liquidity of the strips market. Stale prices in strips imply that opportunities for arbitrage apparent in the data could not always be exploited in practice. So this is a probable explanation for at least some of the apparent arbitrage opportunities. But the strips package is overpriced, allowing for bid-ask spread, in 13,821 (21.1%) of our sample of price differentials, compared with 3,651 (5.6%) in which the gilt is overpriced. Stale prices lead to no prediction about the sign of the price differentials, and so it is unlikely that stale prices are the reason for the much higher frequency of overpricing in strips packages. We infer that many of the arbitrage gaps in our sample are not due to stale strips prices, and so the results of this study represent an anomaly for those who are persuaded that the law of one price must hold in the financial markets. As Schultz & Shive (2010) conclude for dual-class shares, and as Grinblatt & Longstaff (2000) conclude for the US bond market, our evidence from the UK gilts market points towards limits to arbitrage activity in financial markets, and the limits are not fully understood.

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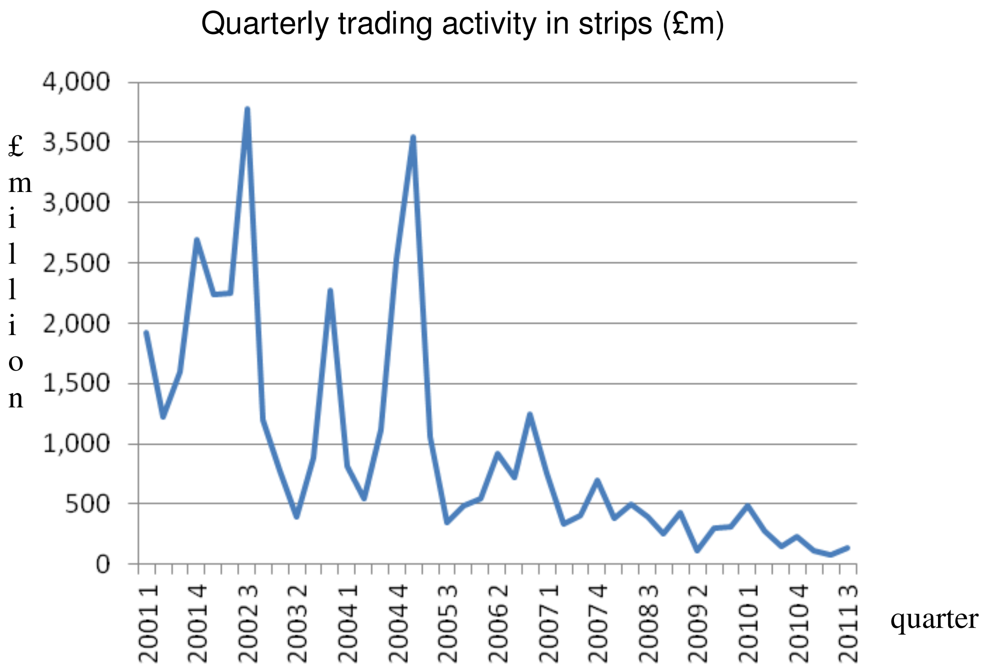
Figure 1



Quarterly trading activity in strips (£m)
£ million
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
2001 1
2001 4
2002 3
2003 2
2004 1
2004 4
2005 3
2006 2
2007 1
2007 4
2008 3
2009 2
2010 1
2010 4
2011 3
quarter

Table 1
UK strippable gilts during 8 December 1997 to 25 November 2011

The gilts are sorted by redemption date. Observations = the number of trading days in the sample period, and the number of price differentials, for the relevant gilt.

Name of Gilt	Redemption date	Strippable from	Observations
8% Treasury Stock 2000	07-Dec-00	08-Dec-97	757
7% Treasury Stock 2002	07-Jun-02	08-Dec-97	1132
6½% Treasury Stock 2003	07-Dec-03	11-Dec-97	1511
5% Treasury Stock 2004	07-Jun-04	23-Jun-99	1250
8½% Treasury Stock 2005	07-Dec-05	08-Dec-97	2020
7½% Treasury Stock 2006	07-Dec-06	08-Dec-97	2273
4½% Treasury Stock 2007	07-Mar-07	25-Mar-04	745
7¼% Treasury Stock 2007	07-Dec-07	08-Dec-97	2526
5% Treasury Stock 2008	07-Mar-08	09-Sep-02	1391
4% Treasury Stock 2009	07-Mar-09	27-Jun-03	1442
5¾% Treasury Stock 2009	07-Dec-09	30-Jul-98	2870
4¾% Treasury Stock 2010	07-Jun-10	21-Jan-05	1357
4¼% Treasury Gilt 2011	07-Mar-11	27-Jan-06	1291
3¼% Treasury Gilt 2011	07-Dec-11	19-Dec-08	741
5% Treasury Stock 2012	07-Mar-12	02-Apr-02	2442
5¼% Treasury Gilt 2012	07-Jun-12	22-Jun-07	1122
4½% Treasury Gilt 2013	07-Mar-13	13-Jun-08	875
2¼% Treasury Gilt 2014	07-Mar-14	17-Apr-09	661
5% Treasury Stock 2014	07-Sep-14	23-Oct-02	2285
4¾% Treasury Stock 2015	07-Sep-15	30-Oct-03	2042
8% Treasury Stock 2015	07-Dec-15	08-Dec-97	3529
4% Treasury Gilt 2016	07-Sep-16	26-May-06	1393
5% Treasury Gilt 2018	07-Mar-18	10-Aug-07	1087
4½% Treasury Gilt 2019	07-Mar-19	21-Nov-08	760
3¾% Treasury Gilt 2019	07-Sep-19	12-Aug-09	580
4¾% Treasury Stock 2020	07-Mar-20	08-Jun-05	1638
3¾% Treasury Gilt 2020	07-Sep-20	07-Jul-10	353
8% Treasury Stock 2021	07-Jun-21	08-Dec-97	3529
3¾% Treasury Gilt 2021	07-Sep-21	06-Apr-11	162
4% Treasury Gilt 2022	07-Mar-22	29-Apr-09	653
5% Treasury Stock 2025	07-Mar-25	02-Apr-02	2442
4¼% Treasury Gilt 2027	07-Dec-27	06-Dec-06	1257
6% Treasury Stock 2028	07-Dec-28	21-May-98	3417
4¾% Treasury Gilt 2030	07-Dec-30	09-Jan-08	982
4¼% Treasury Stock 2032	07-Jun-32	28-Sep-00	2821
4½% Treasury Gilt 2034	07-Sep-34	07-Sep-09	552
4¼% Treasury Stock 2036	07-Mar-36	29-May-03	2151
4¾% Treasury Stock 2038	07-Dec-38	28-May-04	1897
4¼% Treasury Gilt 2039	07-Sep-39	03-Jul-09	608
4¼% Treasury Gilt 2040	07-Dec-40	07-Dec-10	245
4½% Treasury Gilt 2042	07-Dec-42	12-Sep-07	1065
4¼% Treasury Gilt 2046	07-Dec-46	08-Jun-06	1385
4¼% Treasury Gilt 2049	07-Dec-49	03-Dec-08	753
4¼% Treasury Gilt 2055	07-Dec-55	08-Dec-05	1508
		TOTAL	**65500**

Table 2
Descriptive statistics for the strip-conventional price differential

The strip-conventional price differential is the price in £ of a replicating package of strips minus the price of the relevant conventional gilt, with a face value of £100. Daily prices of gilts and principal and coupon strips were obtained from the UK Debt Management Office, and we calculate the daily values of replicating packages from the strip prices.

PANEL A: Entire Sample Period (08 December 1997 to 25 November 2011 inclusive)

		Percentile						
	Mean	0.1	0.3	0.5	0.7	0.9	Skewness	Kurtosis
All gilts	0.060	-0.061	-0.012	0.017	0.064	0.191	7.337	79.529
Short	0.022	-0.052	-0.020	-0.004	0.015	0.053	10.740	131.733
Medium	0.074	-0.051	-0.004	0.030	0.072	0.170	8.427	92.641
Long	0.095	-0.101	0.013	0.072	0.139	0.296	4.556	44.866

PANEL B: 08 December 1997 to 03 August 2002 inclusive

		Percentile						
	Mean	0.1	0.3	0.5	0.7	0.9	Skewness	Kurtosis
All gilts	0.080	-0.039	0.002	0.031	0.069	0.151	8.565	82.913
Short	0.056	-0.029	-0.003	0.014	0.037	0.076	9.462	95.058
Medium	0.101	-0.042	0.014	0.050	0.086	0.148	8.088	75.700
Long	0.102	-0.077	0.019	0.074	0.122	0.208	7.704	72.566

PANEL C: 04 August 2002 to 31 March 2007 inclusive

		Percentile						
	Mean	0.1	0.3	0.5	0.7	0.9	Skewness	Kurtosis
All gilts	0.012	-0.070	-0.025	-0.003	0.023	0.090	8.291	105.329
Short	0.005	-0.064	-0.031	-0.014	0.001	0.023	11.148	140.456
Medium	0.032	-0.056	-0.020	0.003	0.028	0.078	11.328	146.217
Long	0.007	-0.137	-0.011	0.030	0.070	0.135	4.443	60.092

PANEL D: 01 April 2007 to 25 November 2011 inclusive

		Percentile						
	Mean	0.1	0.3	0.5	0.7	0.9	Skewness	Kurtosis
All gilts	0.084	-0.060	-0.007	0.031	0.099	0.268	5.679	53.939
Short	0.018	-0.049	-0.018	-0.004	0.016	0.057	10.367	130.841
Medium	0.089	-0.049	0.007	0.046	0.096	0.216	7.041	75.481
Long	0.138	-0.097	0.036	0.110	0.196	0.366	3.583	27.720

Table 3
Mean price differentials per £100 for overpriced and underpriced gilts, net of estimated bid-ask spread, sorted by maturity of conventional gilt

'Conventional overpriced' (strips package underpriced) means that strip-conventional price differential is below the estimated bid-ask spread of 10bp or £0.10. 'Conventional underpriced' (strips package overpriced) means that the price differential is greater than £0.10.

Remaining Time to Maturity (TTM) / years	Conventional Overpriced Observations	%	Mean Price Differential (£)	Conventional Underpriced Observations	%	Mean Price Differential (£)	Difference < Bid-Ask Spread Observations	%	t-statistic for difference in means of absolute price differentials	Z-statistic for difference in numbers over and underpriced
≤1	2	0.05%	-0.8974	30	0.78%	2.773	3,800	99.16%	-2.127	-4.9681
1 < TTM ≤ 2	11	0.26%	-0.0525	35	0.83%	2.762	4,179	98.91%	-16.645	-3.5509
2 < TTM ≤ 3	273	6.05%	-0.0976	67	1.48%	1.432	4,172	92.46%	-8.043	11.4713
3 < TTM ≤ 4	96	2.34%	-0.0737	94	2.29%	0.907	3,916	95.37%	-6.118	0.1468
4 < TTM ≤ 5	157	3.61%	-0.0763	342	7.86%	0.460	3,852	88.53%	-8.533	-8.5658
5 < TTM ≤ 6	143	4.86%	-0.1667	235	7.98%	0.545	2,567	87.16%	-5.878	-4.9015
6 < TTM ≤ 7	84	3.42%	-0.1548	145	5.91%	0.379	2,226	90.67%	-2.669	-4.1356
7 < TTM ≤ 8	53	1.91%	-0.1152	417	15.04%	0.198	2,302	83.04%	-1.937	-18.0593
8 < TTM ≤ 9	29	0.96%	-0.0499	456	15.12%	0.187	2,531	83.92%	-3.883	-20.9410
9 < TTM ≤ 10	156	4.88%	-0.1197	526	16.47%	0.220	2,512	78.65%	-3.845	-15.2617
10 < TTM ≤ 15	268	4.10%	-0.1017	1,885	28.81%	0.253	4,391	67.10%	-10.216	-40.4370
15 < TTM ≤ 20	409	7.74%	-0.1863	1,967	37.23%	0.148	2,908	55.03%	2.786	-38.8034
20 < TTM ≤ 30	542	4.89%	-0.1413	4,562	41.13%	0.177	5,987	53.98%	-3.661	-71.0526
30 < TTM ≤ 40	784	14.85%	-0.2528	2,284	43.25%	0.193	2,213	41.90%	4.530	-33.8488
40 < TTM ≤ 50	644	34.04%	-0.2958	776	41.01%	0.345	472	24.95%	-2.343	-4.4434
Total	3,651			13,821			48,028			

Table 4
Potential profit from arbitrage net of capital gains tax, commission, and bid-ask spread: three examples

The table shows the gain from arbitrage trades in three gilts and their equivalent strips packages, on the dates shown. The trades are (i) short-sell the relevant strips, (ii) purchase £10,000 face value of the gilt, and (iii) strip the gilt and close out the short positions in the strips. The column headed 'Gross gain' shows the gain from these trades before tax and transaction costs. The gain is positive in each case, indicating that the gilt is underpriced in relation to its strips package. 'Tax @ 40%' shows the capital gains tax liability on the difference between the cash raised from short-selling the strips and the sum invested in the relevant gilt (and it assumes that tax is calculated on the gain gross of transaction costs). Commission is assumed to be charged at a rate of £35 on the first £5,000 transacted, and 0.375% on the amount in excess of £5,000, both on the sale of the strips and the purchase of the conventional gilt.[1] 'Bid-ask spread' shows the estimated cost of selling the strips at the bid and buying the gilts at the ask.[2]

	Trade date	Gross arbitrage gain (£)	Tax @ 40% (£)	Commiss-ion (£)	Bid-ask spread (£)	Net arbitrage gain (£)
8½% Treasury Stock 2005	27 May 2005	426.78	-170.71	-110.50	-10.00	135.57
5% Treasury Stock 2012	7 September 2007	249.24	-99.70	-113.30	-5.00	31.24
5% Treasury Stock 2014	29 August 2006	247.70	-99.08	-110.27	-14.00	24.35

Notes:

1. Commission rates are available from http://www.dmo.gov.uk/index.aspx?page=Gilts/FAQ#Gilt_Purchase_and_Sale_Service

2. The bid-ask spreads on these three gilts are from estimates on the DMO website: http://www.dmo.gov.uk/objectView.aspx?format=exceld&id=68863300&page=Gilts/Retail_Brokerage
   Using our 10bp estimate of the spread, the spread in the three examples would be £10.

Table 5
Mean price differentials by gilt, net of bid-ask spread, with % stripped and % reconstituted, sorted by % stripped per year

Note: data for stripping and reconstitution are available for dates from 29 September 2003 only.

Gilt	Conventional overpriced: No. of days[1]	Conventional overpriced: Mean price differential	Conventional underpriced: No. of days[1]	Conventional underpriced: Mean price differential	*t*-statistic for difference in absolute value of means[2]	% stripped per year[3]	% reconstituted per year[3]
3¾% Treasury Gilt 2020	31	-0.0639	86	0.4429	**-9.19**	0.000%	0.000%
4½% Treasury Gilt 2034	14	-0.1172	432	0.2032	**-4.24**	0.000%	0.000%
4¼% Treasury Gilt 2039	45	-0.1483	356	0.1812	**-1.14**	0.000%	0.000%
4¼% Treasury Gilt 2040	5	-0.0294	228	0.3545	**-12.92**	0.000%	0.000%
3¾% Treasury Gilt 2019	26	-0.1068	163	0.2195	**-2.80**	0.009%	0.000%
2¼% Treasury Gilt 2014	30	-0.0472	116	0.4977	**-11.67**	0.021%	0.001%
4% Treasury Gilt 2022	43	-0.0760	202	0.2295	**-5.35**	0.025%	0.003%
3¾% Treasury Gilt 2021	0	-	132	0.2444	-	0.037%	0.000%
4¼% Treasury Gilt 2046	300	-0.2099	655	0.2145	-0.31	0.040%	0.008%
4½% Treasury Gilt 2042	126	-0.1593	635	0.2333	**-3.93**	0.058%	0.018%
4¼% Treasury Gilt 2049	157	-0.2272	418	0.3697	**-3.75**	0.062%	0.026%
5¼% Treasury Gilt 2012	31	-0.0427	24	0.9461	**-3.46**	0.068%	0.028%
4½% Treasury Gilt 2013	25	-0.1109	79	0.2204	-1.36	0.082%	0.045%
4¼% Treasury Gilt 2027	88	-0.2175	715	0.1193	**4.90**	0.092%	0.033%
4¼% Treasury Gilt 2055	453	-0.3009	633	0.2547	**2.66**	0.098%	0.028%
3¼% Treasury Gilt 2011	83	-0.0848	23	0.5136	**-3.38**	0.110%	0.055%
4½% Treasury Gilt 2019	10	-0.0890	252	0.1636	-1.77	0.125%	0.098%
4¼% Treasury Gilt 2011	1	-0.2119	38	0.8850	-	0.143%	0.108%
4¾% Treasury Stock 2020	54	-0.0461	361	0.1738	**-5.76**	0.186%	0.174%
5% Treasury Stock 2008	12	-0.0522	32	0.7722	**-3.66**	0.251%	0.291%
4¾% Treasury Gilt 2030	58	-0.1299	534	0.2232	**-4.33**	0.258%	0.120%
4¾% Treasury Stock 2010	90	-0.1470	10	2.2687	**-264.42**	0.294%	0.143%
4¾% Treasury Stock 2038	333	-0.3852	757	0.1489	**9.75**	0.374%	0.113%
4% Treasury Stock 2009	42	-0.1241	57	0.7938	**-9.06**	0.378%	0.202%
4% Treasury Gilt 2016	59	-0.1435	66	0.3306	**-2.14**	0.381%	0.203%
5% Treasury Stock 2025	160	-0.1536	476	0.1624	-0.37	0.401%	0.331%
5% Treasury Stock 2014	74	-0.1023	55	0.7213	**-4.24**	0.404%	0.328%
5% Treasury Gilt 2018	81	-0.0919	196	0.2284	**-3.20**	0.455%	0.354%
6% Treasury Stock 2028	233	-0.2185	1,272	0.1778	**2.16**	0.517%	0.470%
5% Treasury Stock 2012	38	-0.0237	27	1.4531	**-6.48**	0.553%	0.507%

Table 5 continued

5¾% Treasury Stock 2009	51	-0.0412	204	0.6553	**-10.66**	0.638%	0.620%
4¼% Treasury Stock 2036	179	-0.1537	677	0.1270	1.15	0.673%	0.350%
4¾% Treasury Stock 2015	55	-0.1325	168	0.3002	**-3.28**	0.839%	0.584%
4½% Treasury Stock 2007	107	-0.1456	7	2.1691	**-163.95**	0.986%	0.944%
8% Treasury Stock 2021	164	-0.1475	1,429	0.1812	-1.63	1.122%	1.212%
7½% Treasury Stock 2006	22	-0.0212	157	0.4838	**-4.91**	1.138%	1.109%
8½% Treasury Stock 2005	33	-0.0197	150	0.5052	**-4.54**	1.210%	0.922%
8% Treasury Stock 2015	175	-0.1121	755	0.2032	**-3.18**	1.324%	1.895%
7¼% Treasury Stock 2007	19	-0.0274	168	0.4841	**-5.13**	1.456%	1.528%
4¼% Treasury Stock 2032	129	-0.1197	783	0.1247	-0.26	1.563%	1.515%
5% Treasury Stock 2004	6	-0.0074	119	0.3298	**-5.56**	4.331%	3.503%
6½% Treasury Stock 2003	6	-0.5256	130	0.3365	0.46	N/A[4]	N/A[4]
8% Treasury Stock 2000	2	-0.0193	10	2.3436	**-3.65**	N/A	N/A
7% Treasury Stock 2002	1	-1.7608	34	1.1138	-	N/A	N/A

[1]The number of days during the sample period on which a gilt of the relevant maturity was overpriced or underpriced, after allowing for the estimated bid-ask spread.
[2]The test statistic is in bold font when the value is significantly different from zero at the 5% level.
[3]Equally weighted averages of the percentage stripped or reconstituted in each year of the sample.
[4]Excluded because of small sample size (ten weeks from 29 September 2003 to maturity).

Table 6
Regression analysis of price differential on time to maturity, measured by number of strips in strips package

The regression equation is $PD_{giltj,t} = \alpha + \beta N_{stripsj,t} + e_{j,t}$, where $PD_{giltj,t}$ is the price differential for gilt j on day t, and $N_{stripsj,t}$ is the number of strips in the strips package for gilt j on day t. Standard errors are in parentheses. *** indicates that the coefficient is significantly different from zero at the 1% level of significance.

Dependent variable	Signed price differential	Absolute price differential
Intercept	0.031*** (0.002)	0.046*** (0.002)
Number of strips in strips package	0.001*** (0.000)	0.002*** (0.000)
Adjusted R^2	0.007	0.041
F-stat	478.9	2,798.2
Observations	65,500	65,500

Table 7
Tests for stale prices of strips packages

The table shows the autocorrelation coefficients for the daily returns on each gilt and its equivalent strips package during the sample period. The standard error (SE) is shown next to the autocorrelation. 'Strips minus gilt' is the autocorrelation for the strips minus the autocorrelation for the gilts, followed by the chi-square statistic to test the significance of the difference in the autocorrelations. The chi-squared statistic is calculated using the formula in Ahn et al (2002, p. 671): $T(\rho_s - \rho_g)^2 / 2(1-\gamma_{s,g}^2)$, where T is the number of days (observations) for the relevant gilt, ρ_s (ρ_g) is the autocorrelation of the strips (gilt), and $\gamma_{s,g}^2$ is the correlation coefficient between the strips and gilt return. The chi-squared statistic has one degree of freedom. The regression test report the beta coefficient and the accompanying *t*-statistic from running equation (4) for each gilt-strips pair. *(**)(***) indicates the 10% (5%)(1%) significance level, respectively. The gilts are sorted by redemption date.

	Gilt		Strips package		Strips minus gilt	Chi-square stat	Regression test	
	Autocorrel'n	SE	Autocorrel'n	SE			Beta	*t*-stat
8% Treasury Stock 2000	-0.004	0.036	-0.001	0.036	0.003	0.009	0.653	16.39
7% Treasury Stock 2002	0.010	0.030	0.011	0.030	0.001	0.001	0.596	17.96
6½% Treasury Stock 2003	0.031	0.026	-0.018	0.026	-0.050	4.405	0.440	16.67
5% Treasury Stock 2004	0.034	0.028	-0.002	0.028	-0.036	1.984	0.407	14.70
8½% Treasury Stock 2005	0.029	0.022	0.012	0.022	-0.017	0.675	0.346	14.94
7½% Treasury Stock 2006	0.036*	0.021	0.023	0.021	-0.013	0.489	0.364	17.60
4½% Treasury Stock 2007	-0.016	0.037	-0.013	0.037	0.003	0.006	0.705	15.78
7¼% Treasury Stock 2007	0.036*	0.020	0.024	0.020	-0.012	0.460	0.373	19.63
5% Treasury Stock 2008	0.007	0.027	0.004	0.027	-0.003	0.016	0.528	19.77
4% Treasury Stock 2009	-0.005	0.026	-0.028	0.026	-0.023	0.936	0.490	19.32
5¾% Treasury Stock 2009	0.047**	0.019	0.037**	0.019	-0.010	0.501	0.265	17.60
4¾% Treasury Stock 2010	0.019	0.027	0.024	0.027	0.006	0.051	0.438	17.06
3¼% Treasury Gilt 2011	0.017	0.037	0.014	0.037	-0.003	0.008	0.264	7.09
4¼% Treasury Gilt 2011	0.003	0.028	0.009	0.028	0.006	0.067	0.347	13.24
5% Treasury Stock 2012	-0.010	0.020	-0.004	0.020	0.006	0.152	0.288	18.11
5¼% Treasury Gilt 2012	0.014	0.030	0.033	0.028	0.018	0.566	0.223	9.25
4½% Treasury Gilt 2013	0.014	0.034	0.023	0.034	0.009	0.138	0.165	6.25
2¼% Treasury Gilt 2014	-0.059	0.039	0.015	0.039	0.074	9.300***	0.143	5.90
5% Treasury Stock 2014	-0.015	0.021	0.000	0.021	0.015	1.035	0.232	15.86

Table 7 cont.

	Gilt		Strips package		Strips minus gilt	Chi-square stat		Regression test	
	Autocorrel'n	SE	Autocorrel'n	SE				Beta	*t*-stat
4¾% Treasury Stock 2015	-0.004	0.022	0.017	0.022	0.021	2.143		0.205	14.00
8% Treasury Stock 2015	0.048***	0.017	0.047***	0.017	0.000	0.001		0.206	17.11
4% Treasury Gilt 2016	0.010	0.027	0.029	0.027	0.019	1.564		0.147	9.80
5% Treasury Gilt 2018	0.026	0.030	0.052*	0.030	0.026	2.851		0.104	6.88
3¾% Treasury Gilt 2019	0.029	0.042	0.032	0.042	0.003	0.016		0.102	4.59
4½% Treasury Gilt 2019	0.052	0.036	0.085**	0.036	0.034	4.569**		0.065	4.11
3¾% Treasury Gilt 2020	0.040	0.054	0.104*	0.054	0.063	6.579***		0.106	4.34
4¾% Treasury Stock 2020	0.013	0.025	0.039	0.025	0.025	4.049*		0.129	10.39
3¾% Treasury Gilt 2021	0.065	0.081	0.129	0.080	0.064	3.34		0.131	3.86
8% Treasury Stock 2021	0.053***	0.017	0.052***	0.017	-0.001	0.005		0.136	14.11
4% Treasury Gilt 2022	0.012	0.039	0.062	0.039	0.050	8.831***		0.072	4.35
5% Treasury Stock 2025	0.023	0.020	0.036*	0.020	0.013	2.239		0.089	10.33
4¼% Treasury Gilt 2027	0.080***	0.028	0.084***	0.028	0.003	0.125		0.044	4.80
6% Treasury Stock 2028	0.078***	0.017	0.080***	0.017	0.001	0.025		0.088	11.85
4¾% Treasury Gilt 2030	0.094***	0.032	0.087***	0.032	-0.007	0.577		0.029	3.06
4¼% Treasury Stock 2032	0.067***	0.019	0.070***	0.019	0.002	0.119		0.051	7.65
4½% Treasury Gilt 2034	0.062	0.043	0.115***	0.043	0.053	13.482***		0.066	4.66
4¼% Treasury Stock 2036	0.034	0.022	0.038*	0.022	0.003	0.16		0.055	7.01
4¾% Treasury Stock 2038	0.067***	0.023	0.070***	0.023	0.003	0.159		0.061	7.46
4¼% Treasury Gilt 2039	0.058	0.041	0.091**	0.041	0.033	6.146***		0.047	3.58
4¼% Treasury Gilt 2040	0.050	0.065	0.061	0.065	0.011	0.428		0.030	1.82
4½% Treasury Gilt 2042	0.074**	0.031	0.080***	0.031	0.006	0.440		0.032	3.79
4¼% Treasury Gilt 2046	0.074***	0.027	0.081***	0.027	0.007	0.715		0.035	4.60
4¼% Treasury Gilt 2049	0.084**	0.036	0.085**	0.036	0.001	0.006		0.039	3.49
4¼% Treasury Gilt 2055	0.073***	0.026	0.086***	0.026	0.013	3.208		0.038	5.28

Table 8
Comparison of price differentials between subperiods

The table compares the scale and frequency of price differentials in excess of the bid-ask spread between the first third of the sample period and the last third. All the test statistics are significant at the 1% level.

		Mean		Median		Number		Percentage	
		Strips over-priced	Strips under-priced	Strips over-priced	Strips under-priced	Strips over-priced	Strips under-priced	Strips over-priced	Strips under-priced
From To	08-Dec-97 03-Aug-02	0.285	-0.121	0.059	-0.056	2,335	376	18.80%	3.03%
From To	31-Mar-07 25-Nov-11	0.225	-0.170	0.110	-0.108	9,341	2,039	28.95%	6.32%
Test statistics for differences		*t*-stat 3.68	*t*-stat -3.92	Mann-Whitney stat 56,041,215	Mann-Whitney stat 2,130,849			*t*-stat -21.88	*t*-stat -12.77

Table 9
Mean price differentials net of bid-ask spread, sorted by coupon

The '%' column shows the percentage of price differentials, of the total number of differentials for gilts in the relevant coupon category, that fall within the relevant pricing category. 'Mean price differential' is the mean of the sample falling within the relevant coupon and pricing categories.

	Conventional Overpriced			Conventional Underpriced			Difference < Bid-Ask Spread		t-statistic for difference in	Z-statistic for difference in
Coupon C	Observations	%	Mean Price Differential (£)	Observations	%	Mean Price Differential (£)	Observations	%	means of absolute price differentials	numbers over and underpriced
C < 5%	2,543	8.5%	-0.3100	8,583	28.7%	0.2180	18,791	62.8%	14.351	-65.717
5% ≤ C < 6%	453	3.0%	-0.1984	1,133	7.6%	0.3719	13,303	89.3%	-7.684	-17.640
6% ≤ C < 7%	239	4.8%	-0.3262	1,402	28.4%	0.1925	3,287	66.7%	6.178	-33.154
7% ≤ C < 8%	42	0.7%	-0.1654	359	6.1%	0.5436	5,530	93.2%	-4.928	-16.284
C > 8%	374	3.8%	-0.2190	2,344	23.8%	0.2182	7,117	72.4%	0.044	-42.534